Research article

Study on Evaluating the Hardness of the Sidewalk Pavement

MIE HIGUCHI
Graduate School of Agriculture, Tokyo University of Agriculture, Japan
Email: bamboo @nodai.ac.jp

YASUSHI TAKEUCHI
Faculty of RegionalEnvironmrnt Science, Tokyo University of Agriculture, Japan

HIROMU OKAZAWA
Faculty of RegionalEnvironmrnt Science, Tokyo University of Agriculture, Japan

KEN-ICHI SATO
Fukuoka University, Fukuoka, Japan

Received 15 December 2010 Accepted 27 January 2011

Abstract In Japan, some laws for the pavement, which took into consideration physically handicapped people and senior citizens, were established. In those relevant laws, it is recommended that safety and comfort for all users should be considered when the sidewalks are designed. But the evaluation method of safety and comfort is not established when the sidewalk pavement are constructed. Therefore, the objective of this study is to establish the simple evaluation method of the pavement's hardness that take into consideration safety and comfort of users, especially for handicapped people. Moreover, the SB/GB test and the Portable Falling Weight Deflectometer (PFWD) test were carried out in this study. In SB/GB test, 1 inch steel ball in diameter and a golf ball were used to measure *SB/GB coefficient*s that were calculated from the bounce height of each ball. The PFWD was used to measure *elastic moduli* of pavement. In the previous study, Takeuchi et al. pointed out that the range of an elastic modulus took into consideration safety and comfort of users that is 25-80MPa. However it is hard to obtain PFWD because of an expensive device. By contrast, SB/GB test can be conducted easily by using a golf ball and a steel ball, moreover, it is widely used in Japan. Hence, to simplify the hardness evaluation of sidewalk pavement, *SB/GB coefficient*s were compared with the *elastic modulus*. As the result, it was found that the range of *SB/GB coefficient*s corresponding to the range of 25-80 MPa in the *elastic modulus* were around 20-35% in *SB coefficient* and around 45-65% in *GB coefficient*. The range can be used to evaluate a road surface by cheap, easy and convenient equipment.

Keywords sidewalk pavement, universal design, hardness, *SB coefficient*, *GB coefficient*, *elastic modulus*

INTRODUCTION

Japan is seeing its population rapidly aging and the idea of barrier-free access has become widely accepted. It is also noted that paved roads in agricultural communities, which are primarily utilized by resident pedestrians, are a facility that is fundamental to the operation of a broad range of community activities as well as to the determination of location and active use of social and modernization infrastructure and service facilities in rural areas. The improvement of roads in agricultural communities allows a faster, smoother, and safer movement of goods and people, thereby expanding socio-economic activities in the community and contributing to higher income levels and a better living environment for residents.

In Japan, research efforts have been directed to produce pavement that is comfortable and easy to walk on. Nabeshima et al. (2005) employed the paved surface hardness test (JIS A 6519) in order to identify a suitable hardness for resilient pedestrian pavement. And it was found that a comfort zone lies in the measured range of *impact acceleration* of roughly 80±10 G. Takeuchi et al. (2008) used this range to pursue structural engineering designs for pedestrian pavement with resilience performance based on the *elastic modulus* obtained in Portable FWD testing and the *impact acceleration* from hardness testing of paved surfaces. The *elastic modulus* corresponding to the *impact acceleration* within the hardness range that provides safe and comfortable for pedestrians, including the elderly and wheelchair users, was shown to be from 25 to 80 MPa (Fig.1). The tests used in the study (the Portable FWD test, which measures the elasticity as a parameter for the amount of physical strain caused by the pavement, and the hardness test of paved surfaces) are not easy to perform due to their high cost. For this reason the present study employed SB/GB testing, which is popular in Japan. This simple-to-perform test uses a steel ball and a golf ball. However, the sensitivity of this test is limited, and it can show only rough value ranges for different types of pavement (Fig.2).

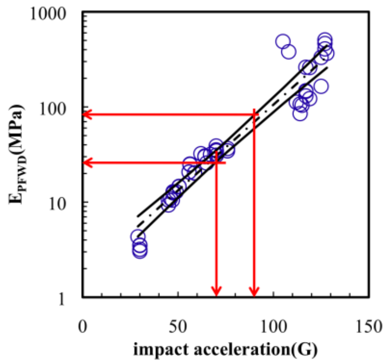

Fig. 1 Relationship between *impact acceleration* and *elastic modulus*

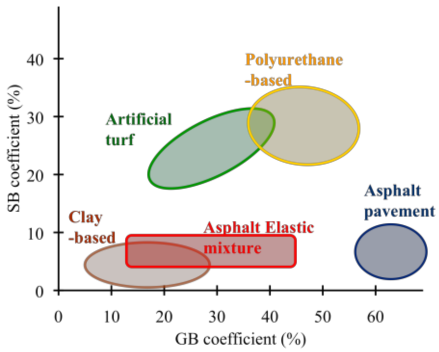

Fig. 2 Relationship between *SB* and *GB coefficient* of each pavement

In order to create a pedestrian environment that is safe and comfortable for senior citizens and the physically handicapped, there is a need to establish a simple testing protocol for pavement elasticity. This paper reports on our SB/GB testing of different paving materials for pedestrian traffic as well as Portable FWD testing for the purpose of developing a simple method to measure pavement resilience to evaluate the comfort level for pedestrians.

SAMPLE LOCATION

In this study, 57 types of pavement were randomly selected as samples. The sample locations are the Setagaya Campus of Tokyo University of Agriculture, the Nanakuma Campus of Fukuoka

University, Sakuragaoka Junior High School, Karasuyamagawa Ryokudo, Togasira Jutaku in Ibaragi, and pedestrian pavements in their surrounding areas, as well as specialty paving in a track field.

Table 1 Sample locations and pavement types

Type of pavement	Number of samples	Type of pavement	Number of samples
Resilient	27	Soil	2
Concrete slab	6	Synthetic resin mixed	2
Clay-based	5	Tile	2
ILB	3	Wood	2
Artificial turf	2	grass	1
Asphalt	2	Other	3

The types of pavement in those locations are shown in Table 1. For the discussion of test results, the measurement data produced by the Pedestrian Pavement Sub-Committee, Pavement Engineering Committee, Japan Society of Civil Engineers were also included.

TEST METHOD

SB/GB tests and Portable FWD tests were conducted for the purpose of measuring the resilience of the paved surface.

SB/GB test

A golf ball and a steel ball are dropped from a height of 100 cm (H) to the paved surface and their respective rebounding heights are measured. The free fall is repeated 5 times for each paving material, and the three most similar rebounds are used to calculate the mean value for rebounding heights (H_0). *SB* and *GB coefficients* are obtained using H_0 in Eq.1. It is believed that the *GB coefficient* reflects impact absorbance, while the *SB coefficient* represents rebound resilience. It is widely held that the smaller these factors are, the less bodily impact a pedestrian would receive. The tests were all performed in accordance with the instructions in the Handbook of Pavement Survey and Testing (Japan Road Association, 2007).

Fig.3 and Fig. 4 show the schematics of the SB/GB tester and how the test was done.

$$SB\ coefficient\ \ and\ GB\ coefficient\ \ [\%] = \frac{H_0}{H} \times 100 \tag{1}$$

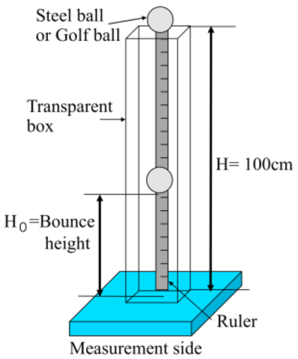

Fig. 3 SB/GB tester detail

Fig. 4 SB/GB testing *in situ*

Portable Falling Weight Deflectometer (PFWD) test

Portable FWD testing involves a load cell that is lifted up by hand and dropped to cause an impact on the paved surface; the impact load and deflection are to be measured. With the loading radius (r) at 0.05 m and the weight at 5 kg, the test was conducted by changing the dropping height to 5 levels from 10 to 50 cm. For each height, the cell was dropped 3 times or more until three similar peak deflection values were obtained. The *elastic modulus*, E_{PFWD} [MPa], was calculated using Eq.2 based on the maximum deflection, D[m], and the maximum load intensity, q [N/m^2], that was derived from the maximum load, P [N] divided by the loading area, A[m^2]. E_{PFWD} refers to the rate of stress-dependent change of displacement. In the case of pavements that incorporate rubber chips, measurements didn't stabilize before the load level reached 3000 N; their E_{PFWD} [MPa] were calculated from the measurements obtained with the maximum load at around 4000 N. E_{PFWD} [MPa], represents a value when the subsurface layers are deemed to be a single layer. In addition, the Poisson ratio, v, is assumed to be 0.4.

Fig.5 and Fig. 6 show the Portable FWD tester and actual testing.

$$E_{PFWD} = \frac{\pi(1-\nu^2)r \cdot q}{2 \cdot D} \times 10^{-6} = \frac{(1-\nu^2)P}{2 \cdot D \cdot r} \times 10^{-6} \quad (2)$$

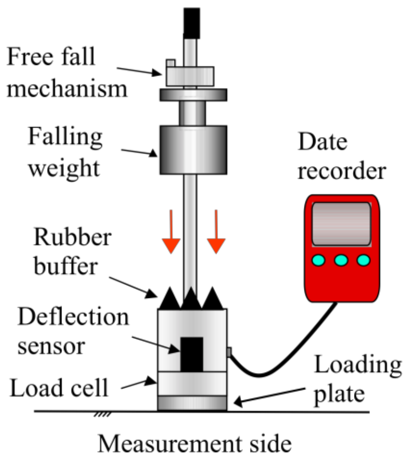

Fig. 5 PFWD tester detail

Fig. 6 PFWD testing *in situ*

RESULTS AND DISCUSSION

The test data were plotted to show the relationship between *SB* and *GB coefficients* (Fig. 7). Statistical analysis classified the data roughly into five groups. It was then decided to exclude the samples where the paved surface is not consolidated, such as artificial turf and soil-based paving, including those akin to clay-based paving and some tile pavements for which the data was rather isolated in the Figures. These samples had uneven top layer surfaces, and test results showed little stability and no correlation between the *SB* and *GB coefficients*. Data for the remaining pavement samples were used to calculate the relationships between *SB coefficient* and *elastic modulus* (Fig. 8), and *GB coefficient* and *elastic modulus* (Fig. 9). These Figures show that both *SB* and *GB coefficients* have a linear relationship with *elastic modulus* in single-logarithmic plotting. Although Takeuchi et al. (2008) did not find any correlations between *SB coefficient* and *elastic modulus*, this study involved more varied pavement samples, which likely produced the linear relationships of Figs. 8 and 9. The dotted line in each Figs. 8 and 9 represents an approximated curve, while the solid lines depict the upper and lower limits of the 99% confidence interval.

The upper limit, 80 MPa, and the lower limit, 25 MPa, of the elasticity range identified by Takeuchi et al. (2008) as appropriate for pedestrian comfort from their hardness testing were plotted on the horizontal axis and vertically extended in each chart to intersect the upper and lower limit lines of the confidence interval to obtain the values of *SB* and *GB coefficients* at the intersecting points. In Figs. 8 and 9 the horizontal arrowed solid lines show the range on the vertical axis that corresponds to the range of *elastic modulus* values and within the confidence interval. In SB and GB tests, results significantly vary depending on the surface condition of the paving material due to the small mass of the measuring apparatus (steel and golf balls). It is therefore assumed that the statistical distribution of data should be taken into account in assessing relationships between results of Portable FWD tests and SB/GB tests where load levels are not the same. Thus the ranges of *SB coefficient* and *GB coefficient* to fit the comfort range of *elastic modulus* were obtained at the confidence interval based on confidence levels of 90%, 95%, and 99%. The measurements obtained in this study are considered to indicate that SB/GB testing of pavements having resilience within the suitable range will produce measurements that fall within the range described in Fig. 8, which has 20% to 35% in *SB coefficient* and 45% to 65% in *GB coefficient* and overlaps partially with the range of polyurethane-based paving.

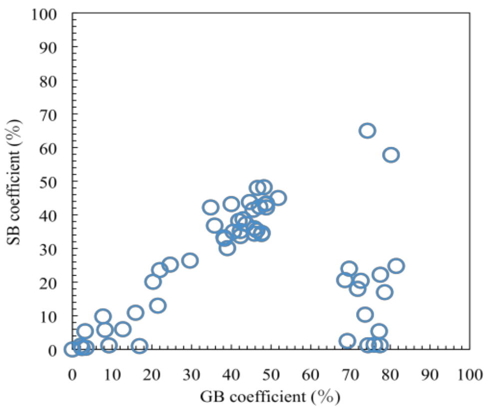

Fig. 7 Relationship between *SB* and *GB coefficients*

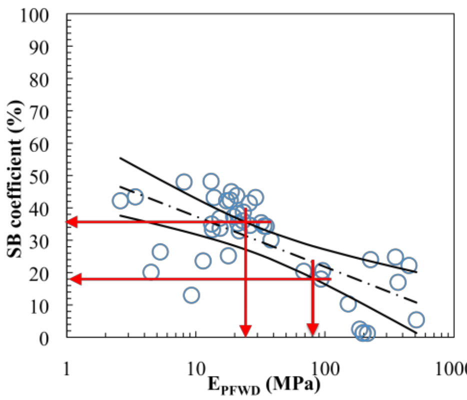

Fig. 8 Relationship between *elastic modulus* and *SB coefficient*

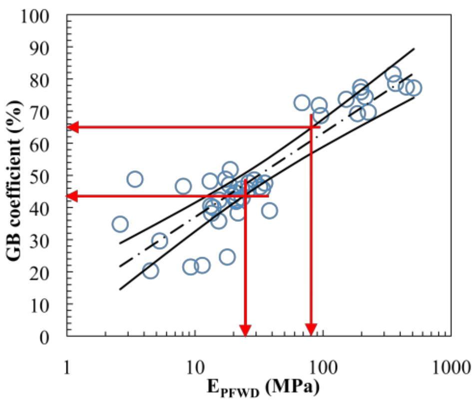

Fig. 9 Relationship between *elastic modulus* and *GB coefficient*

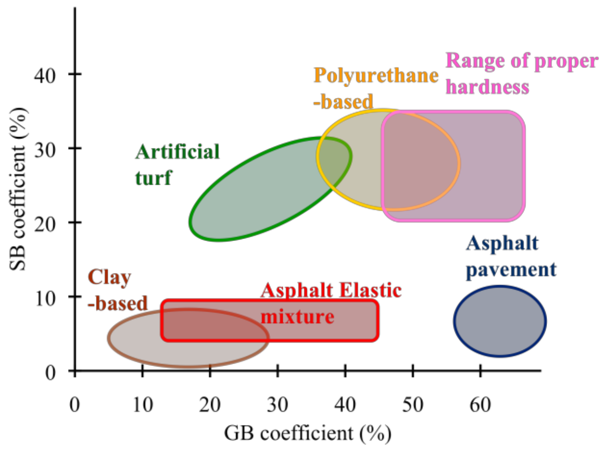

Fig. 10 Indexes commonly used and range of proper hardness

CONCLUSION

The test results suggest the following:

(1) Pavement resilience can be evaluated using only SB/GB tests because *SB coefficient* and *GB coefficient* show correlations with *elastic modulus*.

(2) The appropriate range of elasticity indicated by SB/GB tests is 20% to 35% in *SB coefficient* and 45% to 65% in *GB coefficient*.

These values are, however, applicable only to those pavements containing resin and the like, since the data exclude clay-based materials. We intend to collect more data in order to investigate the reliability of the SB/GB data further. We also plan to study the properties of clay-based pavements in order to revisit the definition of the appropriate hardness range.

ACKNOWLEDGEMENTS

We would like to express our gratitude to members of the Pedestrian Pavement Sub-Committee, Committee on Pavement Engineering, Japan Society of Civil Engineering. The authors are also grateful for the field assistance provided by students of the laboratory of Hydro-structure Engineering, Tokyo University of Agriculture and of the Road & Geotechnical Laboratory of Fukuoka University.

This research was supported by Grant-in Aid for challenging Exploratory Research (20658056) and Grant-in Aid for Scientific Research (B) (22360175) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

REFERENCES

Japan Road Association (2000) Pavement performance rating system in separate volume, Rating system of the performance index to determine as needed, 218-222 (in Japanese).

Japan Road Association (2007) The handbook of pavement survey and testing, the first volume, 126-129 (in Japanese).

Nabeshima, M. and Yamada, M. (2005) Range of proper hardness for aged about walkway pavement, Official journals quarterly of the Japan Society of Civil Engineers, 788-67, 117-126.

Tanaka, K. and Uchida, K. (1989) Evaluation of comfortability and safety on pedestrian road pavement, Annual report of Inst. Civil Engineering of Tokyo Metropolitan Government, 15-26.

Takeuchi, Y., Sato, K., Aoki, M. and Yaginuma, H. (2008) Hardness evaluation of the sidewalk pavement using Portable FWD tester, the proceeding of the 64th JSCE Annual Meeting of the Japan Society of Civil Engineers, (CD-ROMS).